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Some noteworthy features shown by soundings made in the field a depression originating in the north Bay of Bengal during the southwest monsoon season in India.

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Some noteworthy features shown by soundings made in the field of a depression originating in the north Bay of Bengal during the southwest monsoon season in India.

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Abstract.—The chief results obtained from meteorograph ascents made when a depression formed in the Bay of Bengal in July 1937 and moved through Orissa, the Central Provinces and east Rajputana are (*i*) that the tropopause over places lying ahead of the central region of the depression on the ground was lifted up, but it appreciably lowered over the regions in the immediate neighbourhood of the depression as well as over the regions to the north of it; (*ii*) quick fluctuations in the level of the tropopause and in its structure were found to take place after the lowest level was reached; and (*iii*) very low temperatures viz. 183·5°, 186·5° and 188°A were registered over some places affected by it.

1. **Introduction.**—In the southwest monsoon season in India depressions which develop in the Bay of Bengal during July and August travel generally from east to west. In the present paper some peculiar features of the thermal structure of such a depression have been studied in some detail.

2. **Data.**— The isobaric chart of 8 hrs. L.T. on the 10th July 1937 indicated that the weather was markedly unsettled off the Orissa-Circars coast. By the evening of the same day a depression had formed with central region near Lat. 19° N Long. 88°E. It crossed the coast between Puri and Chandbali by 11 hrs. I.S.T. on the 11th July 1937. It lay over the east Central Provinces on the morning of the 12th, over the west Central Provinces on the morning of the 13th and filled up near Kotah in east Rajputana by the morning of the 14th. (See *Fig. 1*).

For the synoptic situation on these dates the Indian Daily Weather Reports of July 1937 may be referred to.

To study the structure of this depression meteorographs of the Dines type were sent up from a number of places. The number of ascents at various places during the period of activity of the depression and the number of records recovered are given in *Table 1*. Two hourly ascents were made only at Sambalpur on the 12th July 1937. The data from these ascents have been published by the India Meteorological Department in the Upper Air Data, Vol. 10, Part B, 1937.

TABLE I.

Station.	No. of ascents.	No. of records recovered.
Calcutta (Alipore)	6	1
Gaya	6	3
Allahabad	9	7
Vizagapatam (Waltair)	8	1
Sambalpur	18	7
Jubbulpore	9	5
Hyderabad (Deccan)	5	3
Agra	12	6
Jodhpur	8	1
Total .	81	34

N.B.—The unusually low levels and temperatures of the tropopauses recorded in the present paper are noteworthy although the reason for them is not clear. One source of uncertainty is that in the Dines meteorographs sent up from Allahabad at 1800 hrs. on the 12th, from Sambalpur at 1413 hrs. on the 12th and from Hyderabad at 1050 hrs. on the 13th, there were largish zero-shifts of the pressure scale and although corrections have been made for these shifts in the same way as for smaller shifts, there is some uncertainty about them.

Editor.

3. **Lowering of the tropopause.**—In two previous papers[1] by one of the authors it has been shown from data of meteorograph soundings at Agra when two depressions moved from the Bay of Bengal through the central parts of India in August 1929 and September 1932 and reached the neighbourhood of Agra, there was a lowering of the tropopause over Agra accompanied by a rise of temperature in the lower stratosphere. In these two cases the upper air over Agra was the outer (probably the outermost) region of the atmosphere affected by the respective depressions which had begun to fill up at the time of the soundings. In the present case soundings at different places, and therefore in the upper air differently affected by the depression, have been made. The soundings confirm the conclusions arrived at in the previous two papers. The results are as follows. (See *Figs. 2* and *3*).

The curves for Sambalpur show the fluctuations in the tropopause as the depression moved westwards. The ascent at 1200 hrs. on the 12th went up to only 105 mb (16·1 gkm). Though it cannot be fixed with certainty, it is very probable that the level of the tropopause is at 15·9 gkm. (108 mbs). But the next ascent at 1413 hrs. shows that the tropopause has lowered to 14·35 gkm. The unmistakable perturbations in the levels near the tropopause shown by this record are apparently caused by the depression.

The ascent at Allahabad at 1013 hrs. on the 12th (*Fig. 3*) gives the level of the usual inversion at 100 mb (16·98 gkm). characteristic of the tropopause in north India during the monsoon season; but perturbations below that level at about 16 gkm. are clearly noticeable. The fluctuations in the tropopause as seen from the series of ascents at Allahabad are fairly similar to what occurred at Sambalpur. The ascent at 1430 hrs. shows a lowering of the tropopause to 16·33 gkm. The lowering is more striking in the next ascent at 1800 hrs. The height of the tropopause as shown by this record viz. 14·1 gkm. (145 mbs) is unusually low for this season in north India.

The ascent at Gaya on the 12th July at 18 hrs. (*Fig. 3*) shows two rather more than usually separated traces at ascent and descent. This record may at first sight be regarded as quite doubtful. The meteorograph which was sent up from Gaya was found just south of Benares at a distance of about 115 miles to the west of Gaya and only about 80 miles to the east southeast of Allahabad. In one of the traces the level of the tropopause is at 15·74 gkm. (112 mbs) and in the other at 13·67 gkm. (158 mbs). The trace which shows the higher tropopause may be taken to correspond to the conditions of the atmosphere in the neighbourhood of Gaya and the other to those near Benares. Considering that the ascent at Allahabad at about the same time indicated the level of the tropopause at 14·1 gkm. the height of 13·67 gkm. for the tropopause near Benares, a place nearer to Allahabad than Gaya is quite possible.

A few words here are necessary regarding the accuracy of the data over Allahabad as obtained from the record of the ascent at 18 hrs. on the 12th. The record showed a large zero shift of pressure. Hence it is possible that the height of 14·1 gkm. for the tropopause deduced from this record may be slightly in error; but the occurrence of the low temperature of 188°A need not be regarded as doubtful. A particle of air from the region of the tropopause which is at 13·67 gkm. and 200°A as shown by one trace of the Gaya record would have to be raised adiabatically only to 14·85 gkm. to attain 188°A if no other physical process but adiabatic ascent alone was operating, i.e. only 0·75 gkm. higher than the level at which the same temperature occurred over

Allahabad. The occurrence of the superadiabatic lapse-rate just below the tropopause over Allahabad is also quite probable as the Gaya trace with the lower tropopause also shows the same feature. Also, the occurrence of superadiabatic lapse rates over north India in the southwest monsoon season is not an uncommon feature as a number of records over Agra and some over Alipore during this season show the same. The possibility of both the records over Gaya and Allahabad being much in error is therefore a remote one.

The occurrence of the superadiabatic lapse rates just below the level of tropopause cannot be the result of any adiabatic process alone. If the Allahabad and Gaya records are plotted on any aerological diagram one can easily see that the temperatures at the tropopause as recorded by the two ascents cannot be the result of ascent of air from any part of the troposphere over the two places. Hence the superadiabatic lapse-rates and the occurrence of low temperatures at the tropopause therefore point to causes other than cooling by adiabatic ascent of air. This is again referred to in a later section.

The ascent at Hyderabad (Deccan) on the 13th at 1050 hrs. gives the height of the tropopause at 15·4 gkm. (126 mbs). Tropopause over Hyderabad has been occasionally found in July at about this level. As this is the only ascent penetrating into the stratosphere during this depression it is not possible to say whether the level of the tropopause and the structure of the stratosphere were affected by the depression.

Some of the records from the ascents at Jubbulpore which would have been important for knowing the effect of the depression on the upper air during its different stages of development have not been recovered. Consequently information regarding the thermal structure over the place is comparatively scanty. Of the available ones the ascents at 0206 and 1417 hrs. on the 12th July (*Fig. 4*) give the level of the tropopause at 17·54 gkm. (80 mbs) and 17·56 gkm. (80·5 mbs) respectively. On the 13th at 0606 hrs. the level of the tropopause was at 16·45 gkm. (103 mbs). The change in the structure of the tropopause as shown by this ascent as compared to the two on the previous day is noticeable.

The record of the ascent at 1803 hrs. of the 17th July after the depression has disappeared on the ground has been reproduced giving both the curves at ascent and descent. A record showing more than one upward and downward movement in the neighbourhood of the tropopause as in this case has not been obtained previously in India. Whether this is due to icing over the balloon or to some wave like disturbance cannot be determined at present.

Though apparently the depression had filled up on the ground near Kotah in east Rajputana by the morning of the 14th, its effect on the upper atmosphere over Agra even on subsequent days is clearly seen (*Fig. 4*). Over Agra the most common type of stratosphere during this season commences with a sharp inversion at about 16·5 to 17 gkm. But in the four ascents reproduced marked fluctuations in the tropopause are noticeable. The ascent at 1800 hrs. on the 15th shows a low tropopause at 15·2 gkm. with a super-adiabatic lapse rate for about a km. below this level.

4. **Lifting up of the tropopause.**—The record over Agra at 1804 hrs. on the 13th July shows a comparatively high level of the inversion at the tropopause at 17·13 gkm. A similar feature is met with over Jubbulpore at 0206 hrs. on the 12th where the height of the tropopause is at 17·52 gkm. At this time the central region of the depression lay to the east of Jubbulpore. The heaving up of the tropopause over places lying ahead of the depression is also shown in the records over Sambalpur, Jubbulpore and Allahabad reproduced in *Fig. 5* (a, b and c). V. Bjerknes[2] and others have explained the lifting up of the tropopause as due to the anticyclonic motion of winds ahead of a depression.

5. **Do the tropopause and its neighbouring levels oscillate up and down ?**—The records at 0200 hrs. on the 13th at Sambalpur, at 1200 hrs. on the 13th at Allahabad and at 0602 hrs. at Jubbulpore obtained after the tropopause over these places reached its lowest level are significant. They show a much higher level of the tropopause than the ascents just previous to these. The raising of the tropopause after it has come down to its lowest level due to the effect of the depression is to be expected when the depression moves away from the place or dies out as the tropopause tends to return to its normal level. But the records of the ascents subsequent to those mentioned above at Sambalpur and Allahabad show that the tropopause was again coming down. This indicates that a vertical oscillation of the tropopause and levels adjacent to it (both above and below) occurs due to the activity of the depression, causing exchange of momentum between these levels.

6. **Thermal structure in some meridional cross sections of the depression.**

(a) *06-11 hrs. on the 13th July 1937, Allahabad-Jubbulpore-Hyderabad* (*Fig. 6a*).

Up to 9 gkm. temperatures over Allahabad were higher than those over Jubbulpore and Hyderabad. This fits in with the normal relations of temperatures prevailing between the easterly branch of the monsoon over the Gangetic valley and the southwesterly branch over the Peninsula. Above 9 gkm. Allahabad had lower temperatures than those over the other two places. This is due to the continuance above 9 gkm of the low temperature and low tropopause conditions in the upper troposphere which prevailed at 18 hrs. the previous evening. In the case of the Hyderabad record the temperature difference between the ascent and the descent traces were rather more than usual. The dotted lines in *Fig. 6* show the isopleths taking account of the lower temperatures as given by one of the traces. In this case the temperatures over Hyderabad between 9·5 and 12·5 gkm. were practically the same as those over Allahabad but slightly lower than those over Jubbulpore.

(b) *06 hrs. on 14th July 1937—Allahabad-Jubbulpore-Hyderabad* (*Fig. 6b*).

The main features in this case are the lower temperatures level for level over Hyderabad than over the other two places and the occurrence of higher temperatures between 2 and 4·5 gkm. and between 7·5 and 16 gkm. over Jubbulpore than those over Allahabad. The latter is apparently due to heat being released by condensation. Due to the higher ground temperature over Allahabad, the temperatures of the layers of air up to 1·5 gkm. are higher over Allahabad than over Jubbulpore.

7. **Thermal structure in some zonal cross sections.**

(a) *18 hrs. on 12th July 1937—Agra-Allahabad-Gaya* (*Fig. 6c*).

The ascent at Agra unfortunately went up to only 7 gkm.

A progressive increase of temperature from Gaya to Allahabad to Agra is noticed up to 7 gkm. and probably up to 8·5 gkm. though the easterly branch of the monsoon was over all the three places. The lower temperatures over Gaya and Allahabad than over Agra may have been caused by the admixture of air over these places with the air from the southwesterly branch of the monsoon brought in by the depression. The southwesterly branch normally has lower temperatures than the easterly branch up to about 16 gkm.

Between 9 and 13 gkm. the opposite relation holds good between Allahabad and Gaya. This is evidently due to the greater fall of temperature in the upper troposphere over Allahabad than in the corresponding levels over Gaya. If the Gaya trace showing the lower tropopause alone is taken into consideration, the temperatures are very nearly equal between 9·8 and 10·4 gkm.

(b) *6-10 hrs. on 13th July-Agra-Allahabad-Alipore (Calcutta) (Fig. 6d.)*

This cross section again shows a feature similar to the previous one viz. a progressive increase of temperature level for level as we proceed from east to west from Calcutta, except in the layer 2-4 gkm. where Allahabad temperatures are nearly the same or even slightly higher than those over Agra.

Table 2 gives the saturation potential temperatures at 6-10 hrs. on the 13th at the three places.

TABLE 2.

Saturation Potential Temperatures °A.

Ht. Gkm.	0	1	2	3	4	5	6	7	8	9
Agra	300	301	301	300	299	299	298	..	..	..
Allahabad	299	300	300	300	299	299	298	298	298	298
Calcutta	299·6	296	296	296	296	296	297	297	297	297

The normal values of saturation potential temperatures up to 9 gkm in the westerly branch of the monsoon is of the order of 295—297°A and those in the easterly branch 297—300°A. Usually the easterly branch is predominant over Calcutta. But the saturation potential temperatures show that the westerly branch has penetrated over the place having been brought in by the depression. The trajectories of air up to 3 km. reaching Calcutta at 8 hrs. on the 13th also support this.

(c) *04-12 hrs. on the 13th July—Sambalpur-Jubbulpore-Jodhpur (Fig. 6e).*

Humidity data are not available for the ascent at Jodhpur at 1155 hrs. on the 13th July. A portion of the record viz. that corresponding to the region 10-16 gkm. shows the two traces having more than the usual difference in temperatures. The traces seem to be satisfactory. One of the traces shows a superadiabatic lapse-rate between 12·8 and 14·5 gkm. and a lower level of the tropopause at 15·64 gkm. (the mean height from the two traces being 15·93 gkm.)

The cross section Sambalpur-Jubbulpore-Jodhpur is roughly along the direction of movement of the depression. The depression lay over the west Central Provinces on the morning of the 13th July. At all levels from ground to 16 gkm. temperatures increase from Sambalpur to Jubbulpore and from ground to 14·0 gkm. there is a further increase from Jubbulpore to Jodhpur. Above 14 gkm Jodhpur temperatures are slightly lower than over Jubbulpore. If, however, we consider the trace of the Jodhpur ascent to which attention was drawn above, the region of lower temperatures would extend from 12·5 gkm.

The foregoing statements regarding the distribution of temperatures over Jodhpur in relation to that over the other two places would be true only if the temperatures at 6 hrs. on the 13th July over Jodhpur were not very different from those at 12 hrs. the same day; whether this was so, it is not possible to say.

The existence of higher temperatures over Jubbulpore and Jodhpur as compared to the temperatures over Sambalpur is due to the latter being in the westerly branch of the monsoon while Jodhpur was affected by the easterly branch. Jubbulpore was also affected by the easterly branch. (This is supported by the data of saturation potential temperatures not given here).

8. The occurrence of low temperatures near the tropopause and superadiabatic lapse rates in the upper levels of the troposphere.—It is known that in the layers 10-14 gkm. over Agra, adiabatic or superadiabatic lapse rates are extremely rare in winter. But in the monsoon season a good many records over Agra and a few over Calcutta and other places show adiabatic or superadiabatic lapse rates in these levels. Ananthakrishnan[3] has suggested that this can be explained as due to cooling by radiation of the layers between 12 and 14 gkm. in the manner first shown by F. Albrecht[4] and referred to by V. Bjerknes and others[5].

It is also well known that during the southwest monsoon season a region of high pressure exists over the Gangetic valley and to its north in the levels 8 to 18 gkm. Data of upper winds at high levels recently collected by Venkiteshwaran[6] show that in July and August winds in the layer 10-14 gkm. within this region of high pressure are decidedly weaker (speeds 10-20 m.p.h.) compared to winds at same levels in lower latitudes (40-50 m.p.h.). Consequently the effects of radiative cooling will be more marked in the region of weaker winds within the region of high pressure and it is possible that more cooling due to radiation may result in such low temperatures at these levels as found in the present case. Under the influence of the depression, the cooled air mass from this region of high pressure may either flow towards the region affected by the depression along an isentropic surface or suffer subsidence ; in the latter case with an increase of temperature.

Palmen[7] has shown that in the case of extra tropical cyclones subsidnig air masses are not found to be as warm as one would expect them to be. He finds that air which had originally a temperature of—55°C descends approximately by 4 km. to a height of 5·1 km, the lower limit of the stratosphere, where the temperature instead of being —15°C is actually —30°C. He suggests that this cooling by 15°C is due to heat radiation. Refsdal[8] has shown that the effect of this cooling by radiation in the Albrecht layer of air which suffers subsidence due to cyclone activity is to force the tropopause to assume a lower level.

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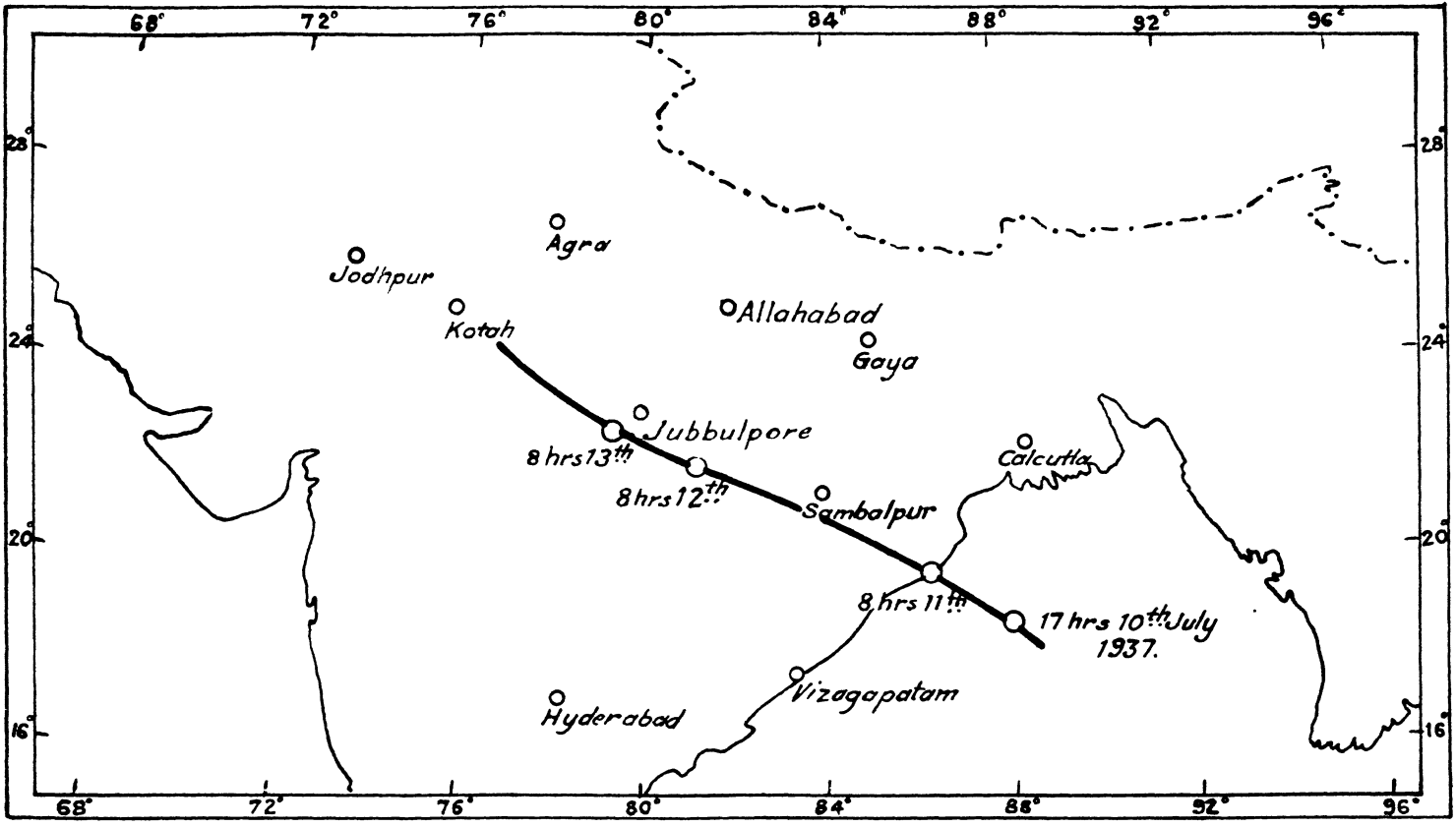

FIG. 1. TRACK OF THE DEPRESSION

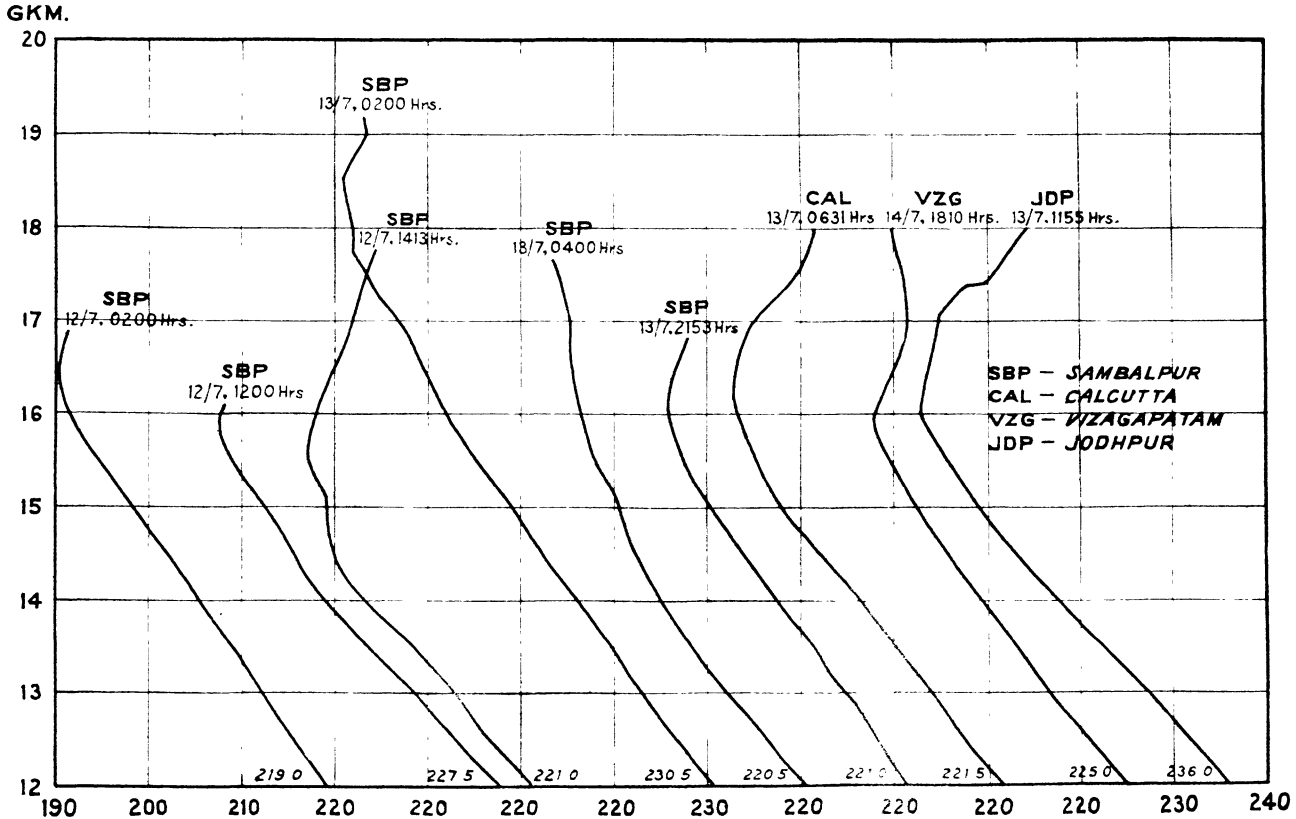

FIG.2.

G P.Z.P POONA '46

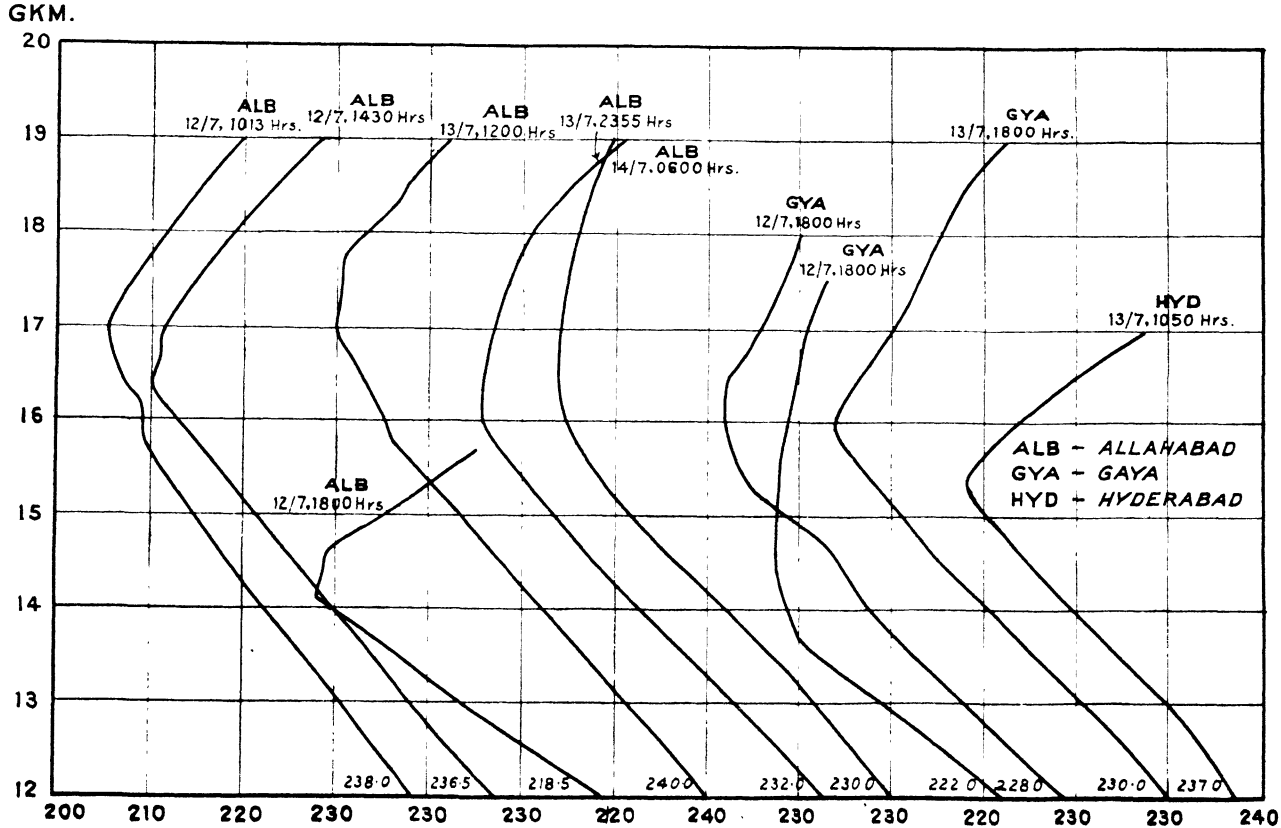

FIG. 3.

G.P.S.I.P. POONA '46

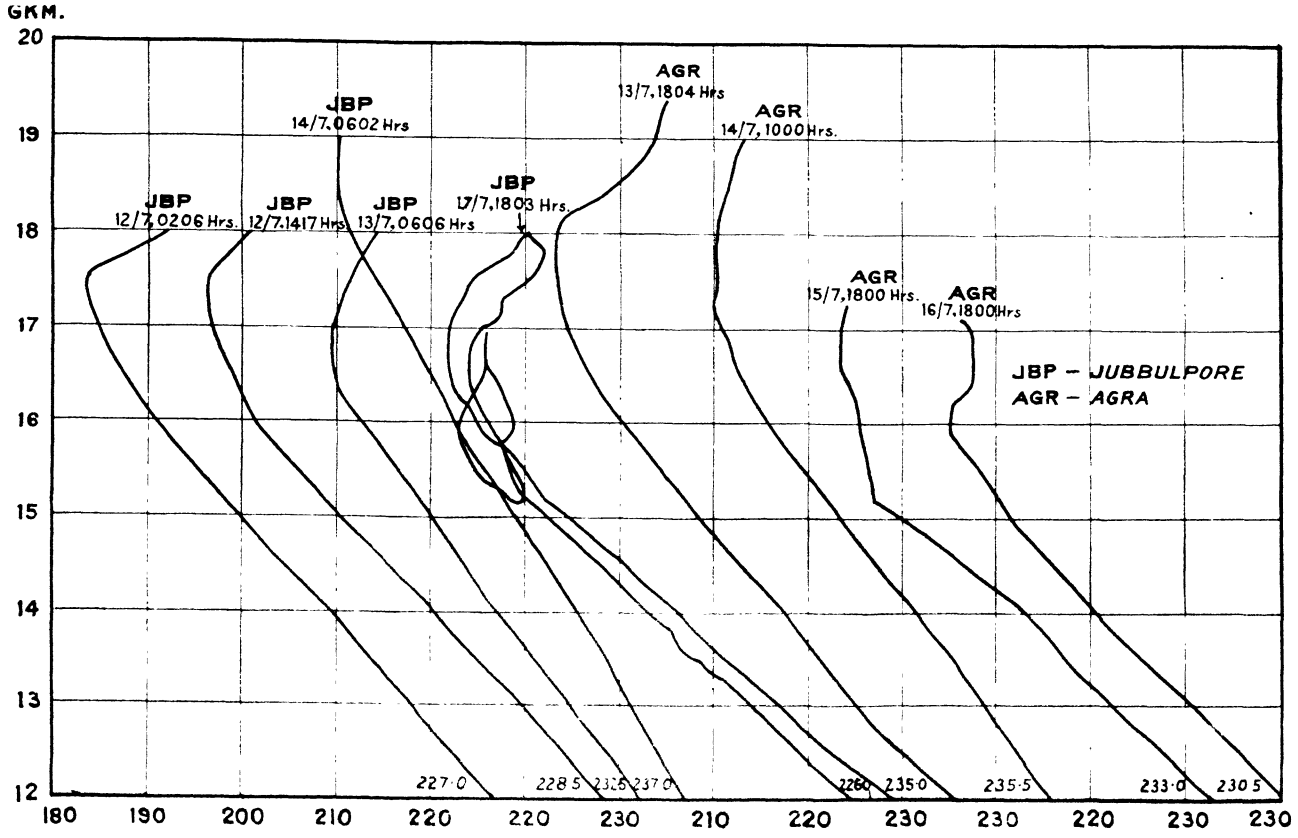

FIG. 4.

GPZ PPOONA/46.

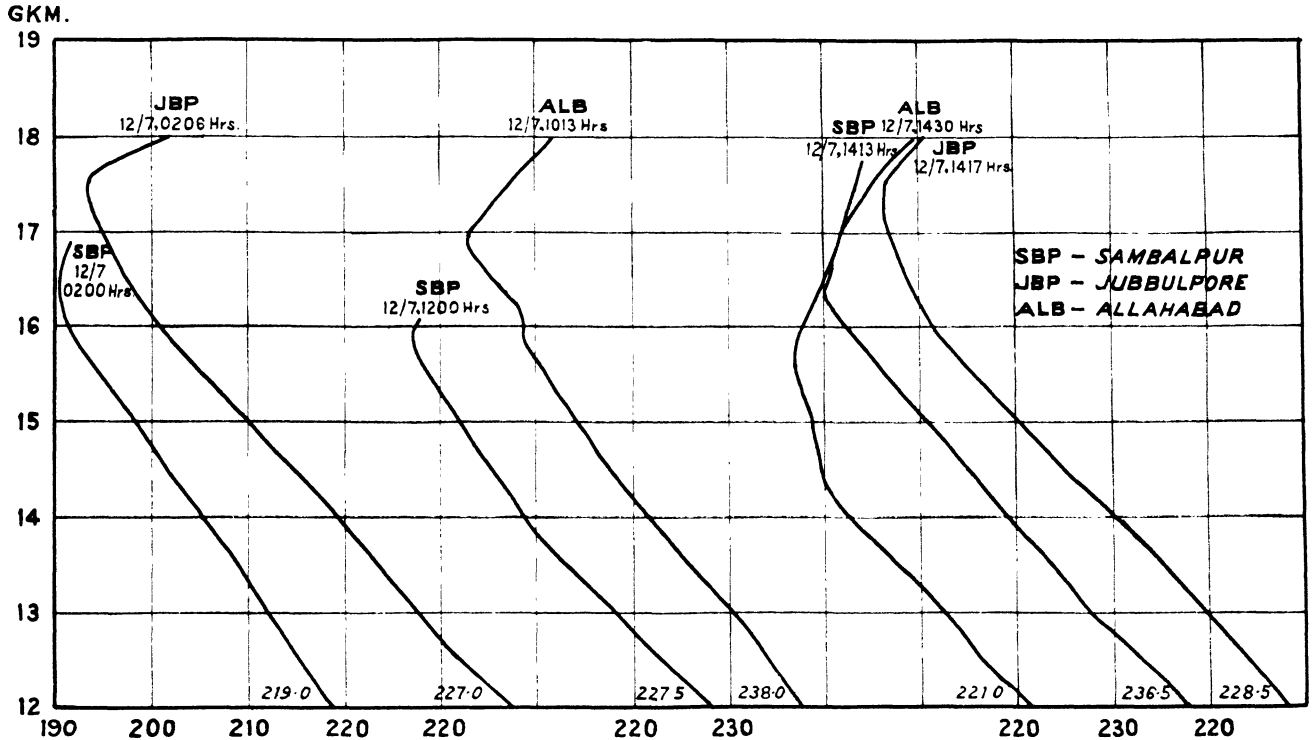

FIG. 5.

G.P.Z.P. POONA/46.

KM.
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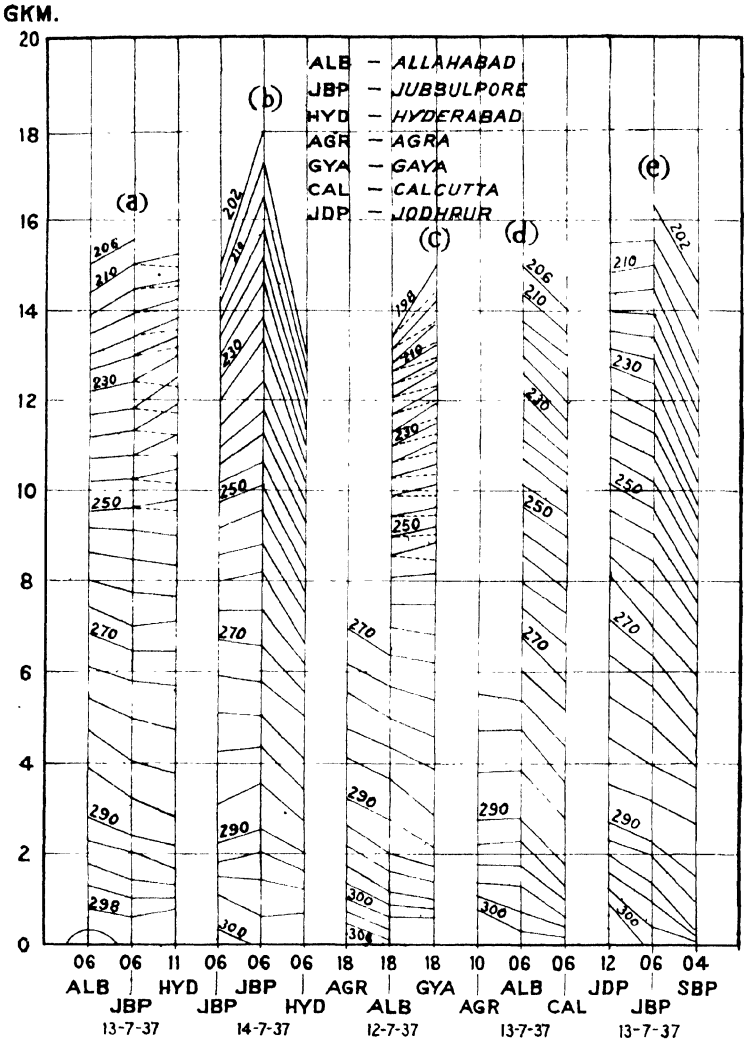

FIG. 6.

KM.
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